A gas injector for a furnace or boiler gas-fired burner has a plurality of peripheral openings around a center opening. The peripheral openings are pitched radially away from the longitudinal axis of the gas injector and also pitched either clockwise (CW) or counter-clockwise (CCW), to impart a swirling motion to gaseous fuel exiting the injector through the openings. The gas injector with the radial plus CW or CCW pitched peripheral openings has reduced flame length and lower CO emissions and only slightly elevated levels of NOx emissions relative to a gas injector with only radially pitched openings. The gas injector is useful in furnaces having small enclosures to prevent burner flames from impinging on the opposing walls.
GAS INJECTORS FOR SHORT FLAME AND LOW POLLUTANT EMISSIONS

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates generally to the field of commercial and industrial power generation, and in particular to a new and useful injector for gas-fired burners used in furnaces.

There are four main methods for firing natural gas in large-scale, commercial fossil fueled burners. Two of these methods, depicted in FIGS. 1A and 1B, contemplate a plurality of separate, equally spaced natural gas injection nozzles (spuds) mounted in the swirling air zones near the burner exit. In a third method, multiple longitudinal spuds are arranged in a circular array, as shown in FIG. 1C. As can be seen in FIGS. 1A, 1B and 1C, these three burner arrangements all employ a common manifold to distribute the natural gas among a multitude of gas spuds, adding a substantial level of undesirable complexity. The burner arrangements of FIGS. 1A and 1B also require the spuds to be placed in fixed positions in the air zones. Notably, each individual spud may have one or more holes drilled into it in order to direct gas flowing therethrough.

Undesirable complexity is further compounded in burners designed to fire both gas and pulverized coal, either alone or in combination, using multiple axial gas spuds. The spuds are difficult to fit in the burner without interference with the coal nozzle and elbow assembly, and are not easily retracted for protection from heat and slag during coal-only firing.

In contrast, the fourth arrangement, shown in FIG. 1D, employs a single gas injection nozzle, i.e. a single gas injector or “super spud”, positioned in the center of the burner. In this fourth arrangement, natural gas flows from a pipe into a large, single gas element and disperses through multiple holes drilled at its discharge tip. Known super spud elements do not impart any swirling component to the discharged gas, so that the natural gas is discharged from the injection holes with only axial and/or radial velocity components, i.e. without a tangential component to the velocity. FIGS. 4A and 5A illustrate such a prior art single gas injection 100a in which each injection hole 120 is formed straight through the end wall 170 of the injector 100a. The injection holes 120 are arranged equally spaced around a center hole 110.

Previous firing of natural gas at 100 million Btu/hr in a large-scale test facility via multiple spuds in a fossil fuel burner, similar to the arrangement shown in FIG. 1A, resulted in acceptably short or transparent flames, but with high NOx concentrations (>600 PPMV or 0.7 lb NOx/10^10 Btu). This arrangement did not include the use of flue gas recirculation (FGR) or overfire air (OFA). FGR is a proven NOx reduction technique in which a portion of flue gas from the boiler exit is mixed with the secondary air and introduced into burner. NOx levels can also be reduced by using OFA, which is a process where part of the combustion air is diverted from the burner and injected above the flame zone for substoichiometric burner operation.

Large-scale testing of a burner equipped with multiple axial spuds encircling the inner wall of a central core pipe, similar to the arrangement shown in FIG. 1C, achieved lower NOx concentrations (165 PPMV NOx or 0.18 lb NOx/10^10 Btu) compared to the arrangement of FIG. 1A, and produced 16 PPMV CO at 9% excess air and 100 million Btu/hr, again without FGR or OFA. Under these conditions the flame length was 24-26 feet. While these levels of NOx, CO and flame length are presently acceptable, this arrangement, as noted above, is mechanically complex.

Single element centerline, or super spud, firing of natural gas in three different fossil fuel burners, using an arrangement similar to FIG. 1D, generated 67 to 88 PPMV NOx (0.08 to 0.10 lb NOx/10^10 Btu) with luminous, 28 to 30 ft long flames at 100 million Btu/hr firing rate and 9% excess air level.

As demonstrated by the above results, single element centerline (super spud) gas firing, via the arrangement of FIG. 1D, seems to be more attractive than firing by multiple spuds, via the arrangement of FIG. 1C, due to low NOx emissions and mechanical simplicity. Nevertheless, despite the significantly lower NOx emissions, natural gas injection through a single centerline super spud has resulted in long flame lengths. These longer flames can impinge on the opposite walls of shallow depth boilers or furnaces, resulting in poor heat absorption and deterioration of combustion.

In contrast, the arrangements of FIGS. 1A and 1B, with spuds mounted in the swirling air zones, produce short or transparent flames, but with high NOx performance. Multiple longitudinal spuds in the burner core zone, the arrangement of FIG. 1C, generated higher NOx levels than the centerline super spuds, in addition to luminous flames exceeding the length of those observed for peripheral spuds.

Therefore, a better way of discharging natural gas and other gaseous fuels from fossil fuel burners is needed to reduce the flame length without significantly increasing the NOx emissions.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a gaseous fuel injector for a burner, which simultaneously produces short flames and low CO and NOx emissions via unique drilling patterns. The gas injector is connected to a supply pipe extending to the burner opening at the furnace wall. The drilling pattern in the injector imparts a swirling action to the gaseous fuel jets as they emerge from the discharge holes. Mixing between the gaseous fuel and air is improved relative to non-swirling fuel jets, resulting in significant reductions in the flame length and CO emissions, and NOx emissions comparable to other single gas injectors.

Accordingly, in one embodiment, the subject invention provides an injector for discharging a gaseous fuel through a burner into a furnace or boiler for producing a shortened burner flame with low levels of CO and NOx emissions. The injector includes a chamber for transporting the gaseous fuel along a flow path, and has a longitudinal chamber axis and an endwall. Several peripheral openings are circumferentially spaced about the chamber axis on the endwall. Each opening has an inlet, an outlet, and a longitudinal opening axis. Each opening axis is inclined at a first acute angle greater than zero with respect to the chamber.
axis, and is further inclined, in a direction toward an adjacent peripheral opening, at a second acute angle greater than zero.

[0013] It is another object of the invention to provide a burner assembly designed to fire both gas and pulverized coal and having a gas injector that is easier to fit in the burner without interference with the coal nozzle and elbow assembly.

[0014] It is yet another object of the invention to provide a burner assembly designed to fire both gas and pulverized coal and having a gas injector that is easily retracted for protection from heat and slag during coal-only firing.

[0015] Accordingly, in a second embodiment, the subject invention provides a burner assembly for burning a gaseous fuel that produces a shortened flame with low levels of CO and NOx emissions. The assembly includes a chamber for transporting the gaseous fuel along a flow path, and has a longitudinal chamber axis and an endwall. Several peripheral openings are circumferentially spaced about the chamber axis on the endwall. Each opening has an inlet, an outlet, and a longitudinal opening axis. Each opening axis is inclined at a first acute angle greater than zero with respect to the chamber axis, and is further inclined, in a direction toward an adjacent peripheral opening, at a second acute angle greater than zero. An annulus surrounds the chamber concentric with the chamber axis and has an outlet adjacent the endwall. The annulus can be used for transporting air or a mixture of air and pulverized coal.

[0016] The various features of novelty which characterize the invention are pointed out with particularity in the claims annexed to and forming a part of this disclosure. For a better understanding of the invention, its operating advantages and specific objects attained by its uses, reference is made to the accompanying drawings and descriptive matter in which a preferred embodiment of the invention is illustrated.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] In the drawings:

[0018] FIGS. 1A, 1B, 1C and 1D are prior art natural gas injector arrangements.

[0019] FIG. 2 is a partial sectional view of a burner arrangement suitable for burning pulverized coal and/or natural gas in a furnace using the gaseous fuel injector of the invention;

[0020] FIG. 3 is a sectional side view of an individual gas injector;

[0021] FIG. 4A is an end view of a prior art gas injector, including the orientation of the injection openings;

[0022] FIGS. 4B and 4C are end views of the present invention, including the orientation of the injection openings;

[0023] FIG. 5A is a sectional view showing the orientation of a prior art gas injector, including the orientation of the injection openings;

[0024] FIGS. 5B and 5C are sectional views showing orientations of gas injectors according to the present invention, including the orientation of the injection openings;

[0025] FIG. 6 is a graph illustrating flame length in feet for each of a straight injection opening, a clockwise injection opening and a counter-clockwise injection opening injector;

[0026] FIG. 7 is a graph illustrating CO levels in PPMV for each of a straight injection opening, a counter-clockwise injection opening and a clockwise injection opening injector;

[0027] FIG. 8 is a graph illustrating NOx levels in PPMV for each of a straight injection opening, a counter-clockwise injection opening and a clockwise injection opening injector;

[0028] FIGS. 9 and 10 are partial sectional views of pulverized coal and natural gas burner arrangements for a furnace used to test the gas injector of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0029] Referring now to the drawings, in which like reference numerals are used to refer to the same or similar elements, FIG. 2 shows a burner 10 for a furnace having a gaseous fuel supply pipe 50 with a gas injector element 100 attached to the end extending through the furnace wall burner opening 40. Air stream 59 for combustion enters around the pipe 62 and flows into the annulus 67 with swirl vanes 70 for distribution and mixing of air with combustion gases in the flame as it exits the opening 40. A gaseous fuel 55, such as natural gas, is provided in supply pipe 50. In a variation of the invention, primary air and pulverized coal may also be injected via annulus 57 into the burner 10, either separately, or with a gaseous fuel supplied simultaneously via pipe 50.

[0030] The gas injector element 100 is preferably positioned in the center of the burner 10 in burner throat 30. However, gas injector element 100 may be horizontally displaced within the burner 10 as well.

[0031] In use, a gaseous fuel 55, such as natural gas, passes through the supply pipe 50 to gas injector element 100, where it is injected into the furnace and ignited. Typically, a horizontally extending flame is generated at the gas injector element 100. Ideally, the flame from each burner 10 in a furnace extends across the furnace enclosure, but does not impinge on the opposing wall.

[0032] The gas injector element 100, as shown in section in FIG. 3, can be secured to the end of the supply pipe 50 via a threaded or welded connector 150. Inner walls 160 define a chamber 165 having several injector openings 110, 120 in the end wall 170. The center opening 110 may increase in diameter from the inner wall 160 to the exterior of the gas injector element 100. As shown in FIG. 3, peripheral injector openings 120 are most preferably oriented with their longitudinal opening axes 122 at a distinct first acute angle α in comparison to the longitudinal chamber axis 112. Ideally, α is between 10° to 45° relative to the longitudinal chamber axis 112, and most preferably set at about 40°, although greater and smaller angles are possible. This radial orientation of the peripheral openings 120 provides a diverging flow of gaseous fuel 55 as it leaves the gas injector element 100. Notably, the arrangement depicted in FIG. 3 can illustrate features common to both the prior art and the present invention. When the gas injector element 100 is secured to the supply pipe 50, gaseous fuel 55 passes
into chamber 165 and exits through the peripheral openings 120 and center opening 110 into the furnace for combustion.

[0033] What sets apart the present invention from the prior art is the pitched angle or tilt of the peripheral openings 120 that results in a swirling gaseous fuel flow pattern with superior performance characteristics. FIGS. 4A and 5A show the prior art arrangement wherein the orientation of the axes 122 of the peripheral openings 120 clearly creates a diverging pattern, but without imparting swirl to the gas exiting openings 110, 120.

[0034] In contrast, FIGS. 4B and 4C distinctly illustrate two gas injector elements 100b and 100c according to the present invention. Each of the gas injector elements 100b and 100c of FIGS. 4B and 4C has peripheral openings 120 which are circumferentially spaced about chamber axis 112, and preferably has eight peripheral openings 120 which are spaced 45° apart. Unlike the prior art gas injector element 100a of FIG. 4A, the peripheral openings 120 in the elements 100b and 100c of FIGS. 4B and 4C are drilled through the gas injector end wall 170 at a second acute angle, or pitch angle β, relative to the surface of the end wall 170. The angle β is defined by the intersection of an opening axis 122 with a reference line 128. As best seen in FIG. 3, reference line 128 extends from the chamber axis 112 at the above-mentioned first acute angle α. As shown in FIGS. 4B and 4C, reference line 128 intersects opening axis 122 at the opening outlet 126 of opening 120. The pitched orientation of the openings 120 provides a rotational (i.e., angular or tangential) velocity component to natural gas 55 passing through the peripheral openings 120.

[0035] FIGS. 5B and 5C illustrate more details of the pitch angle β for the peripheral openings 120 relative to reference line 128. As shown in FIG. 5B, the peripheral openings 120 are set with the opening axis 122 oriented with a left pitch or angle β, for example about 15°, relative to reference line 128. The left pitch gives the natural gas fuel jets exiting the peripheral openings 120 a counter-clockwise (CCW) tangential spin (as viewed from the furnace looking toward the front of gas injector 100b) relative to the longitudinal chamber axis 112. The CCW tangential spin causes the natural gas 55 to swirl in a counter-clockwise direction as it discharges radially and axially from gas injector 100b through peripheral openings 120. This is in contrast to prior art injector 100a, shown in FIG. 5A, wherein β is zero, and opening axis 122 and reference line 128 coincide. FIG. 5C illustrates a gas injector element 100c of the present invention having a clockwise (CW) tangential spin provided by a 15° right pitch for each peripheral opening 120.

[0036] The combustion airflow supplied through the burner 10 around the gas injector element 100 may also be provided with swirl pattern, produced by swirl vanes 70, as shown in FIG. 2. The direction of the combustion air swirl pattern can be the same or opposite to that for the CW- or CCW-oriented peripheral openings 120. The gaseous fuel swirl pattern is directly attributable to the pattern of pitched openings, and the inventors believe performance is substantially enhanced in comparison to the prior art designs described above.

[0037] The gas injector elements 100b and 100c according to the present invention produce shorter flame lengths with reduced CO emissions and only slightly increased NOx emissions relative to the prior art conventional gas injection elements discussed above.

[0038] The gas injector elements 100b, 100c are designed preferably for use in burners 10 firing natural gas at a design flow rate although they may be used in higher or lower capacity situations. In a preferred embodiment, the gas injector elements is sized to accommodate several gas injection holes. The center opening 110 and the peripheral openings 120 are sized for natural gas injection velocities of 40,000 to 80,000 feet per minute at standard conditions.

[0039] FIGS. 6-8 show the benefits of using gas injector elements 100b and 100c having the CCW- and CW-oriented peripheral openings 120 in a furnace. The results displayed in each of FIGS. 6-8 were obtained as follows.

[0040] Natural gas firing using a single, centerline gas injector element inside the coal nozzle of a Babcock & Wilcox plug-in DRB-XCL PC burner (a registered trademark of The Babcock & Wilcox Company) was evaluated in a large-scale test facility. The burner was equipped with a recessed flame cone 80 and a multi-blade coal nozzle impeller 70 mounted around the centerline gas injector element, as shown in FIG. 9. The outer secondary air zone contained both fixed vanes 82 and adjustable vanes 84, and inner secondary air zone contained adjustable vanes 84. Several gas injector elements having different drilling patterns and injection hole diameters were installed in the burner separately for testing.

[0041] Among all gas injector elements 100 tested, the elements 100b and 100c, with either counter-clockwise or clockwise drilling pitches to the peripheral openings 120 had better overall performance with regard to NOx, CO, and flame length.

[0042] For example, as shown by FIG. 6, the 100 million Btu/hr gas injector element 100b with CCW-oriented peripheral openings 120 produced a 23-ft. flame. Gas injector element 100b resulted in emissions of 72 PPMV CO at 10% excess air and 93 PPMV NOx (0.11 lb NOx/10^6 Btu), as illustrated in FIGS. 7 and 8, respectively.

[0043] Under the same operating conditions, the flame length, CO emissions, and NOx emissions for the gas injector element 100c with CW-oriented peripheral openings 120 were 23 feet, 67 PPMV CO, and 124 PPMV NOx (0.14 lb NOx/10^6 Btu) as seen in each of FIGS. 6-8, respectively.

[0044] By comparison, at the nominal conditions of 100 million Btu/hr and 10% excess air, the conventional gas injector element 100a with the straight peripheral openings of FIGS. 4A and 5A had a flame length of 28-30 feet, emitted 170 PPMV CO, and achieved 85 PPMV NOx (0.10 lb NOx/10^6 Btu). These results are also shown in FIGS. 6-8, respectively.

[0045] In a further test, a plug-in DRB-XCL PC burner was reconfigured as illustrated in FIG. 10, with an air distribution device, or air separation vane, 86 and a gas injector element 100 with peripheral openings 120 (i.e., gas injector elements 100b and 100c, as shown in FIGS. 4B and 4C) designed for a 70 million Btu/hr firing rate with natural gas. Gas injector element 100c (with CW-oriented periph-
eral openings 120) produced a flame length of only 17 feet, and emissions of 20 PPMV CO and 131 PPMV NOx (0.15 lb NO2/106 Btu), when operated at 70 million Btu/hr and 10% excess air. Under the same operating conditions, gas injector element 100b (with CCW-oriented peripheral openings 120) produced an 18 foot flame length and emissions of 15 PPMV CO and 122 PPMV NOx (0.13 lb NO2/106 Btu).

Although gas injector elements 100b and 100c, having eight peripheral openings 120 with opening axes 122 inclined at first acute angle α of about 400 with respect to the chamber axis 112, and a second acute angle or pitch angle β of about 15° CCW (100b) or CW (100c) had the best overall performances, it is anticipated that the number and diameter of the holes, pattern, and drilling angle (first angle and second, or pitch angle) could vary to suit the performance needs of particular applications. The precise variations will depend on the specific boiler/furnace geometry, firing rate, and desired emissions performance and flame shape and other factors.

While a specific embodiment of the invention has been shown and described in detail to illustrate the application of the principles of the invention, it will be understood that the invention may be embodied otherwise without departing from such principles.

1. An injector for discharging a gaseous fuel through a furnace burner wall opening into a furnace or boiler for producing a shortened burner flame with low levels of CO and NOx emissions by providing a swirl gaseous fuel flow pattern exiting from the wall opening the injector comprising:

   a chamber for transporting the gaseous fuel along a flow path to the furnace burner wall opening, the chamber having a longitudinal chamber axis, and an endwall located adjacent the furnace burner wall opening;

   a plurality of peripheral openings circumferentially spaced about the chamber axis on the endwall, each opening having an inlet, an outlet, and a longitudinal opening axis, each opening axis inclined at a first acute angle between about 45° with respect to the chamber axis;

   wherein each opening axis is further inclined, in a direction toward an adjacent peripheral opening, at a second acute angle between about 10-30° defined by the angle between the opening axis and a line extending from the chamber axis at the first angle and intersecting the opening axis at the opening outlet, to provide a rotational velocity component to the gaseous fuel passing through the plurality of peripheral openings.

2. (canceled)

3. A gas injector according to claim 1, wherein the peripheral openings are evenly spaced about the chamber axis.

4. A gas injector according to claim 1, wherein the gaseous fuel is natural gas.

5. A gas injector according to claim 1, further comprising a central opening positioned on the endwall aligned with the chamber axis.

6-12. (canceled)

13. A burner assembly for producing a shortened burner flame through a furnace burner wall opening of a furnace or boiler with low levels of CO and NOx emissions when fired with a gaseous fuel by providing a swirling gaseous fuel flow pattern exiting from the wall opening, the assembly comprising:

   a chamber for transporting the gaseous fuel along a flow path to the furnace burner wall opening, the chamber having a longitudinal chamber axis, and an endwall located adjacent the furnace burner wall opening;

   a plurality of peripheral openings circumferentially spaced about the chamber axis on the endwall, each opening having an inlet, an outlet, and a longitudinal opening axis, each opening axis inclined at a first acute angle between about 10-45° with respect to the chamber axis, wherein each opening axis is further inclined, in a direction toward an adjacent peripheral opening, at a second acute angle between about 10-30° defined by the angle between the opening axis and a line extending from the chamber axis at the first angle and intersecting the opening axis at the opening outlet, to impart swirl to the gaseous fuel passing through the plurality of peripheral openings; and

   an annulus surrounding the chamber concentric with the chamber axis and having an annulus outlet adjacent the endwall.

14. The burner assembly of claim 13, further comprising a central opening positioned on the endwall concentric with the chamber axis.

15. The burner assembly of claim 13, wherein the annulus is for transporting air.

16. The burner assembly of claim 15, further comprising means, adjacent the annulus outlet, for swirling the air flowing through the annulus.

17. The burner assembly of claim 16, wherein the peripheral openings impart swirl to the gaseous fuel in a first rotational direction and the means for swirling the air imparts swirl to the air in the same rotational direction.

18. The burner assembly of claim 16, wherein the peripheral openings impart swirl to the gaseous fuel in a first rotational direction and the means for swirling the air imparts swirl to the air in a second rotational direction different from the first rotational direction.

19. The burner assembly of claim 13, wherein the annulus is for transporting a mixture of air and pulverized coal.